A METHOD OF APEXOCARDIOGRAPHIC ANALYSIS OF ISOVOLUMETRIC CONTRACTION, TENSION AND EJECTION OF THE LEFT VENTRICLE

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The oustanding clinical importance of isovolumetric contraction (IVC), tension (T) and ejection (E) of the left ventricle justifies the interest in their accurate and easy determination. A great variety of methods are known for their analysis. In the course of comparative investigation (16) of the different methods of IVC determination, it has been made clear that the method of *Oreshkov* (2, 3, 4, 13) has highest degree of precision.

In a previous work we demonstrated that the openings of aortic valves may be determined only with the aid of apexicardiogram (ACG) without resorting to other reference curves: a streight line is drawn joining two points on the ascending shoulder of the ACG, situated at the site of closure of the mitral valve and distant 20 msec from the first point. The moment corresponding to the deviation of the ACG ascending shoulder drift from the straight line corresponds to the opening of the aortic valves.

Since the opening of the aortic valves is a key moment in the analysis of IVC, T and E we made it our aim to verify the extent to which the cardiac cycle phases referred to lend to analysis solely on the basis of ACG.

Material and Method

A series of 30 healthy individuals were subjected to investigation. All the subjects underwent polygraphic recording, including ECG lead II, phonocardiogram (PCG), carotissphygmogram (CSG) and ACG. The recordings have been described in an earlier publication. The comparative study comprises seven methods.

IVC was determined after the method of Oreshkov and two new procedures (Fig. 1).

Method 1 (Oreshkov): from the beginning of the ACG systolic (ACG b) wave to the beginning of CSG (CSG b) minus the time of pulse wave delay (TPWD); IVC $= ACG_b - (CSG_b$ minus TPWD).

Method 2 (newly suggested): from the beginning of the systolic wave of ACG to the real E point (E_r) (from «ejection») of the ACG, i. e. to the opening of the aortic valves; IVC $= ACG_b - E_r$.

Method 3 (newly suggested): the electromechanical interval (EMI) is subtracted from the tension time, i. e. from the beginning of the electric systole to the opening of the aortic valves minus EMI; IVC $=$ (qECG$- E_r$)

minus EMI. The latter is determined from the beginning of q to the beginning of the systolic shoulder of ACG.

The tension time (T) was determined after the method of Holdak /(/ and according to a newly suggested method (Fig. 2).

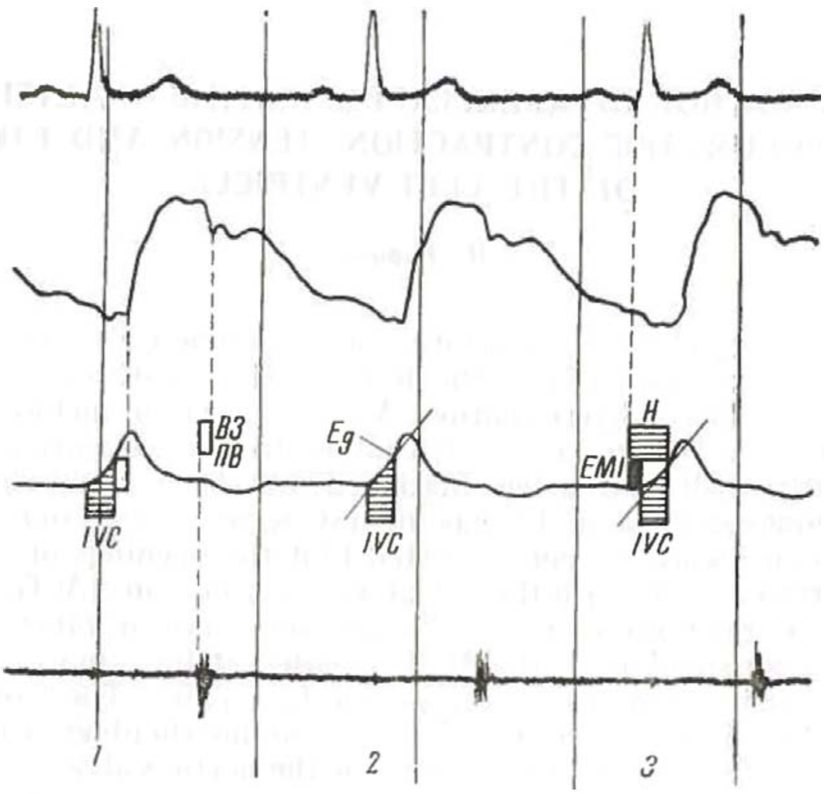

Fig. 1. Patient No. 24, direct recording 50 mm/sec ECG, lead II CSG, ACG, PCG, 140 Hz, analysis of isovolumetric contraction

1. Method of Orehskov: $IVC = ACG_b$ — (CSG_b minus TPWD). 2. New method: $IVC = ACG_b - E_r$. 3. New method: IVC—(qECG—E_r) minus EMI. All three methods produce equal results; in this case 80 msec.

Method 4 according to *Holdak:* from the beginning of the electric systole to the beginning of CSG minus the time of pulse wave delay; T= =qECG—(CSG minus TPWD).

Method 5 (newly suggested): from the beginning of the electric systole to the opening of the aortic valves; T=qECG—E_r.

The ejection time was determined according to the classical method of *Blumberger* (9) and according to a new method (Fig. 3).

Method 6 suggested by *Blumberger:* from the beginning of the CSG to the lowest point of the incisure; E=CSG_b—INC.

Method 7 (newly suggested): from the opening of the aortic valves determined by the ACG to the beginning of the aortic component of the second heart sound in the PCG; E=E_h—A_2.

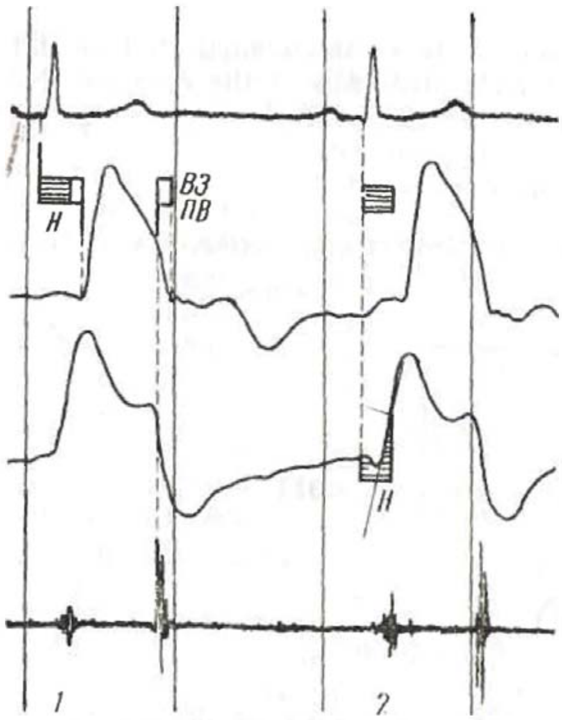

Fig. 2. Patient No. 12, direct recording 50 mm/sec *ECG*, lead *II*, *CSG*, *ACG*, *PCG*, 140 *Hz*, analysis of the time of tension

1. Method of Holdak: T=qECG — (*CSG* minus *TPWD*). *2*. New method: $T = qECG - E_r$. Both methods yield equal results; in this case 100 msec.

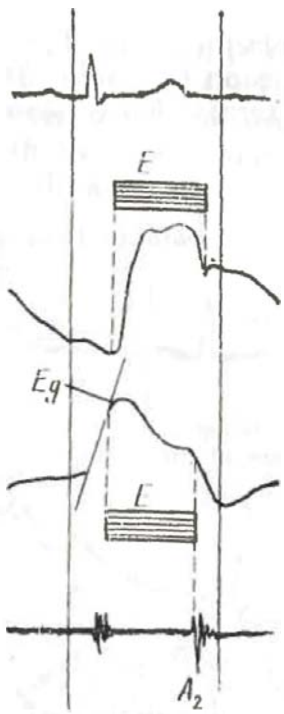

Fig. 3. Patient No. 13. direct recording 50 mm/sec. ECG lead *II*, *CSG*, *ACG*, *PCG* 140 *Hz*; analysis of ejection

The CSG illustrates the method of Blumberger: $E = CSG_b$ — inc. The ACG illustrates the new method: $E = E_r - A_2$. Both methods include the protodiastole. The results are equal (290 msec). In the *CSG*, the ejection is recorded with 20 msec delay owing to the delayed pulse wave.

Results

From the analysis of Table 1 it becomes evident that the methods suggested for the determination of IVC duration (methods No. 2 and 3), insofar precision is concerned do not differ essentially from the method of Oreshkov (No. 1).

Table 1

Comparative Data for IVC in msec

Indices	Method No.				
	1	2	t	3	t
Mean standard	65,66	66,66		65,66	
Deviation	±14,16±	9,33		±14,16	
Standard error of the mean	+ 6,78±	4,49	0,86	— 6,78	0
Range	40—90	50—90		40—90	

It is obvious from Table 2 that the methods suggested for determination of the tension time (No. 5) and the duration of the ejection (No. 7) do not differ in terms of precision from the unversally accepted classical methods.

Table 2

Comparative Data about the Tension and Ejection Time in msec

Indices	Method No.					
	4	5	t	6	7	t
Mean	96	95,33		286	286,33	
Standard deviation	±7,54	±10,89		±14,97	±26,08	
Standard error of the mean	±3,55	±5,23	0,32	± 7,16	±12,42	0,30
Range	80–120	80–120		250–310	250–320	

Discussion

Oreshkov (13) makes a comprehensive review of the issue concerning the beginning and termination of IVC. It may be assumed as proved that (4, 16) IVC initiates with the very first mechanical phenomena, indicating the initial ventricular contraction which starts with the contraction of the papillary muscles of the heart (14) and the intramural pressure rise the myocardium of the left venticle (11) and not with the start of the pressure rise (1, 5, 6) within the ventricular cavity. These initial mechanical phenomena are detected most accurately with the ACG (4, 16, 17).

Methods similar to apexcardiography such as kinetocardiography (12) are capable of detecting only some of the mechanical phenomena in the left ventricle prior to the pressure rise (16).

Since the beginning of IVC is best determined with ACG (the beginning of the ACG systolic shoulder) it is preferable also to employ ACG for determination of the termination of IVC. It ends with the beginning of ejection, i. e. with the opening of the aortic valves. The aortic valves are opened prior to the systolic peak of ACG (4, 10, 15, 16, 18) erroneously accepted by *Benchimol and associates* (7, 8) as the beginning of ejection. The authors who determine the aortic valves' opening by the systolic peak of ACG (the so-called E point) report higher values for IVC than the real ones. Whenever additional reference curves are employed for the determination of the aortic valves' opening, the methods become more complicated.

The procedure herein suggested for IVC determination solely on the basis of ACG has a high level statistical reliability and is superior in comparison with other methods in terms of simplified pattern and accuracy. Bearing in mind the great clinical importance of IVC (1, 5, 6, 16), ACG appears to be a very convenient reference curve for the clinical practice in the determination of this phase of the heart cycle.

The *tension* time represents a cumulative interval including the phases contained between the beginning of the electric systole and the beginning of the ejection. *Holdak* (6) determines it by the ECG, CSG and PCG. If the time of tension is determined with the aid of ACG instead of CSG (Method No. 5) the results are virtually equivalent. As the tension is not investigated separately, but invariably in conjunction with IVC it is more convenient to resort to ACG for the purpose because, as already pointed out IVC is determined with highest precision on the basis of ACG. After determination of the tension time the IVC might be calculated by subtracting from the tension time the electromechanical interval (Method No. 3).

As most accurate among the indirect methods for EJECTION-phase determination those could be accepted making use of CSG (Method No. 6). There is a dispute (1, 5) whether one should accept as the end of ejection — the beginning of the incisure of CSG or else the end of the descending part of the incisure. The descending part of the incisure corresponds to the protodiastole (1) but nevertheless many authors (6, 15, 17) include it in the phase of ejection regardless of the methods available for determination of the protodiastole by the CSG (1).

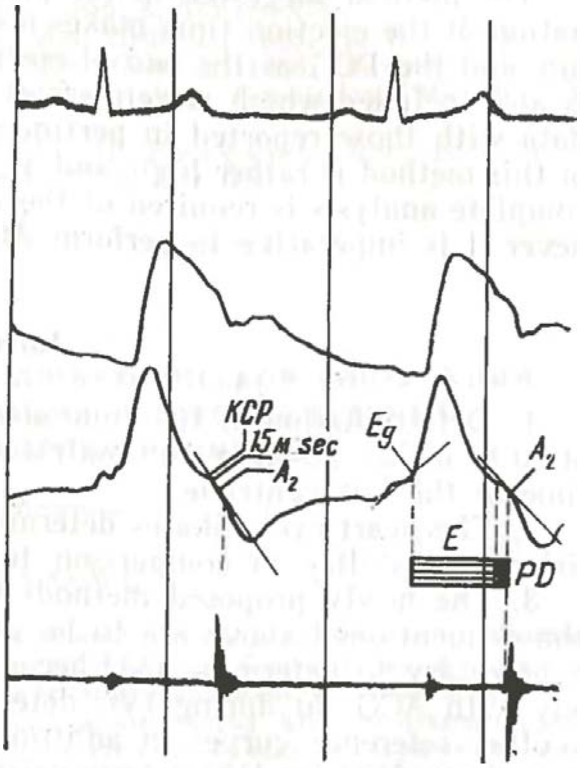

Fig. 4. Patient No. 14, direct recording, 50 mm/sec, *ECG* lead *II*, *CSG*, *ACG*, *PCG* 140 *Hz*

Determination of the time of aortic valves' closure — A_2 (first heart contraction): two points are placed, one at the end of the systolic shoulder (*ESS*) and the other at 15 msec distance from it. A straight line is drawn joining the two points. The moment at which the descending arm of the ACG is deflected from the straight line corresponds to A_2. Analysis of the ejection (*E*) and protodiastole (*PD*) separately (second heart contraction); *E*= =*Ed* — *ESS*; *PD*—*ESS* — A_2.

The ACG determines with great precision the beginning of the ejecttion as well as the end of ejection and the protodiastole also (17). The termination of the ejection corresponds to the end of the systolic shoulder of ACG, whilst the protodiastole begins with the end of the systolic shoulder and ends with the closure of the aortic valves (17). In about half of the cases during the closure of the aortic valves a small notch N_2 is formed along the descending shoulder of ACG (17). According to preliminary data in cases lacking N_2, the time of aortic valves closure may be determined also by ACG. The latter are closed when the pressure within the aorta begins to exceed the falling pressure in the left ventricle. At this moment the isovolumetric relaxation of the left ventricle also starts. It is natural to expect that such a crossing of tension curves would affect the descending shoulder of ACG by altering its direction. The moment (point) of direction shift may be determined in analogical manner as that of the opening of the aortic valves. A straight line tangent to the descending shoulder of ACG is drawn. The straight line is determined by two points. The first point is located at the end of the systolic shoulder of ACG and the second — at 15 msec from the first, running along the course of the descending shoulder (15 msec are equal to the lowest values of protodiastole). The moment in which the descending shoulder deviates from the above mentioned straight line may be assumed as corresponding to the closure of the aortic valves (Fig. 4).

The method suggested in the present work (Method No. 7) for determination of the ejection time makes use of the ACG as beginning of the ejection and the PCG as the end of ejection. It is clear that the protodiastole is also included which is deliberately made in order to obtain comparable data with those reported in pertinent literature. The statistical reliability of this method is rather high and it is preferable to be used whenever a complete analysis is required of the systolic and diastolic phases i. e. whenever it is imperative to perform ACG.

Inferences

1. Determination of the time of opening of the aortic valves solely by of ACG makes possible the analysis of IVC, the tension time and ejection time of the left ventricle.
2. The heart cycle phases determined by the ACG denote sufficient statistical reliability in comparison to other universally accepted methods.
3. The newly proposed methods for computation of the heart activity phases mentioned above are to be preferred to other methods whenever it is necessary to determine IVC because a) IVC is determined most accurately with ACG, b) during IVC determination it is not necessary to resort to other reference curves in addition to the ACG, c) since it is necessary to perform ACG for IVC determination it would be most convenient to use the same reference curve for the analysis of the other heart-cycle phases also. Thus the method is simplified, the required apparatus may be two-or-three channeled and, along with that, time is saved which would be otherwise required for other reference curves' tracings.

The significance of the remaining reference curves, such as carotissphygmogram, phlebogram etc., is by no means contested; their utilization in the clinic has a wide field of application in a variety of cardio-vascular diseases, depending on the aim of investigation.

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МЕТОД ДЛЯ АНАЛИЗА ИЗОВОЛЮМЕТРИЧЕСКОЙ КОНТРАКЦИИ, НАПРЯЖЕНИЯ И ИЗГНАНИЯ ЛЕВОГО ЖЕЛУДОЧКА ПО АПЕКСКАРДИОГРАММЕ

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РЕЗЮМЕ

щаются результаты анализа изоволюметрической контракции, напряжения и изгнания только по данным АКГ у 30 здоровых лиц. Сравнительные исследования показывают наличие необходимой статистической значимости. Изоволюметрическая контракция определяется от начала систолического плеча АКГ до открытия створок аортального клапана. Напряжение определяется от начала электрической систолы до открытия створок аортального клапана, а изгнание — от открытия створок аортального клапана до их закрытия. Изоволюметрическую контракцию можно также вычислить, если из времени напражения вычесть электромеханический интервал. Открытие створок аортального клапана определяется по АКГ при помощи проведения по восходящему плечу АКТ прямой, определяемой двумя точками, находищимся на месте закрытия митрального клапана и на растоянии 20 мсек от первой точки; момент, который соответствует отклонению восходящего плеча АКГ от указанной прямой соответствует открытию аортального клапана.